

Unexpected Superoutburst and Rebrightening of AL Comae Berenices in 2015

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Abstract

In 2015 March, the notable WZ Sge-type dwarf nova AL Com exhibited an unusual outburst with a recurrence time of ~ 1.5 yr, which is the shortest interval of superoutbursts among WZ Sge-type dwarf novae. Early superhumps in the superoutburst light curve were absent, and a precursor was observed at the onset of the superoutburst for the first time in WZ Sge-type dwarf novae. The present superoutburst can be interpreted as a result of the condition that the disk radius barely reached the 3:1 resonance radius, but did not reach the 2:1 resonance one. Ordinary superhumps immediately grew following the precursor. The initial part of the outburst is indistinguishable from those of superoutbursts of ordinary SU UMa-type dwarf novae. This observation supports the interpretation that the 2:1 resonance suppresses a growth of ordinary superhumps. The estimated superhump period and superhump period derivative are $P_{\text{sh}} = 0.0573185(11)$ d and $P_{\text{dot}} = +1.5(3.1) \times 10^{-5}$, respectively. These values indicate that the evolution of ordinary superhumps is the same as that in past superoutbursts with much larger extent. Although the light curve during the plateau stage was typical for an SU UMa-type dwarf nova, this superoutburst showed a rebrightening, together with a regrowth of the superhumps. The overall light curve of the rebrightening was the almost the same as those observed in previous rebrightenings. This implies that the rebrightening type is inherent in the system.

Key words: accretion, accretion disks - novae, cataclysmic variables - stars: dwarf novae - stars: individual (AL Comae Berenices)

1 Introduction

WZ Sge-type stars are an extreme subclass of dwarf novae (Osaki 1995). The origin of unique light variations, as well as their evolutionary status, are still in debate (e.g., Osaki, Meyer 2003; Nakata et al. 2014; see Kato 2015 for a review). Their observational properties are that (1) the amplitude of the superoutburst is large, exceeding ~ 6 mag (Howell et al. 1995), (2) the interval between the successive superoutbursts (super-cycle) is unusually long, typically with a time scale of decades (Kato et al. 2001), (3) modulations with double-peaked profiles called early superhumps are observed in the early phase of the superoutburst (Kato 2002), and (4) after the end of the plateau stage, single or multiple rebrightenings are observed (Imada et al. 2006). Among them, properties (3) and (4) are considered to be unique to WZ Sge-type dwarf novae and to be the defining characteristics (see Kato 2015).

In recent years, our understanding on SU UMa-type and WZ Sge-type dwarf novae has been improved by using extensive photometric data obtained by ground-based and space telescopes (Still et al. 2010; Wood et al. 2011; Osaki, Kato 2013a; Osaki, Kato 2014). Kato et al. (2009) studied superhump period changes and concluded that the $O-C$ diagram of superhump maximum timings is composed of three stages: stage A in which P_{sh} (the superhump period) is long and constant, stage B in which P_{sh} changes as the superoutburst proceeds, and stage C in which P_{sh} is short and constant. Also, Kato et al. (2014b) classified rebrightenings into five types according to the profiles of the light curves. The rebrightening type includes type-A (long duration rebrightening), type-B (multiple rebrightenings), type-C (single rebrightening), type-D (no rebrightening), and type-E (double superoutbursts). Most recently, Kato (2015) published a comprehensive review of WZ Sge-type dwarf novae, in which he suggested that period derivative of superhumps and rebrightening type reflect the evolutionary sequence of the system.

In the case of WZ Sge-type stars, no precursor outburst had been observed (see below), while precursors have been observed in almost all of ordinary SU UMa-type stars except for large-amplitude, rarely outbursting objects (Warner et al. 1995). In ordinary SU UMa-type stars, the disk radius exceeds the 3:1 resonance radius at the onset of their superoutbursts. It takes one or two days for the tidal instability to grow up. Hence, the cooling wave propagates in the disk until the tidal instability fully develops. In the meantime, the brightness gradually decreases like normal outbursts. After the disk becomes eccentric, starting a superoutburst, the brightness rapidly increases (Osaki, Meyer 2002). However, in WZ Sge-type stars, the mass stored in quiescence is large and the cooling front does not propagate before appearance of superhumps (Osaki, Meyer 2003). This is considered to be the reason why the light curves on WZ Sge-type stars had shown no precursors.

AL Com is one of the best known WZ Sge-type dwarf novae, and sometimes called “a perfect twin” of WZ Sge itself. The WZ Sge nature of the system in the modern sense was first elucidated by Kato et al. (1996), who detected early and ordinary superhumps having periods of $P_{\text{Esh}} = 0.05666(2)$ d and $P_{\text{sh}} = 0.05722(10)$ d, respectively, during the 1995 superoutburst. The 1995 superoutburst was studied by many astronomers. Howell et al. (1996) performed V and I photometry and derived a positive $P_{\text{dot}} (= \dot{P}/P$; the time derivative of the superhump period), together with a hint of the presence of stage A and C. Patterson et al. (1996) pointed out that the mass of the secondary star might be below $0.04 M_{\odot}$. Nogami et al. (1997) studied superhump period changes using extensive data and obtained $P_{\text{dot}} = +1.5(3.1) \times 10^{-5}$. AL Com also underwent superoutbursts in 2001 May (Ishioka et al. 2002), 2007 October (Uemura et al. 2008), and 2013 December (Kato et al. 2014a). All of these superoutbursts showed early superhumps and rebrightenings.

On 2015 March 4.582 UT, Kevin Hills reported an outburst of AL Com at a magnitude of $V = 14.528$ (vsnet-alert 18377). Immediately after this report, the VSNET collaboration team (Kato et al. 2004) started a worldwide photometric campaign. Surprisingly, the present outburst turned out to be a superoutburst, despite the fact that the brightness was much fainter than those in past superoutbursts and that the previous superoutburst occurred only ~ 450 d before. Here, we report our observation of AL Com during this unusual superoutburst.

2 Observations and Results

Time-resolved CCD photometry was carried out by the VSNET collaboration team at seven sites. Table 1 (online only supplementary data) shows the log of photometric observations. We also used the data downloaded from the AAVSO archive¹. All of the observation times were converted to Barycentric Julian Date (BJD). The magnitude scales of each site were adjusted to that of the Kolonica Saddle system (DPV in Table 1), where UCAC4 522-052504 (RA: 12h32m10.04s, Dec: +14° 20' 15."4, $V = 13.51$, (Bertola 1964)) was used as the comparison star. The constancy of the comparison star was checked by nearby stars in the same images.

Figure 1(a) represents the overall light curve of the 2015 outburst of AL Com. As can be seen in Figure 1(a), the duration of the plateau stage is ~ 10 d. This duration is significantly shorter than those of previous superoutbursts, for which the plateau stages lasted for 20 d or more (Kato et al. 1996; Ishioka et al. 2002; Uemura et al. 2008; Kato et al. 2014a). In addition, the maximum magnitude was 14.1 mag, about 2 mag fainter than those of previous superoutbursts. It also should be noted that the superoutburst was accompanied by a precursor (BJD 2457086;

¹ < <http://www.aavso.org/data/download/> >.

see Figure 1(b)). The 2015 superoutburst of AL Com is the first case that a precursor was observed in WZ Sge-type dwarf novae. After the termination of the plateau stage, AL Com underwent a rebrightening. The present rebrightening was well classified as the type-A rebrightening (see also Kato 2015).

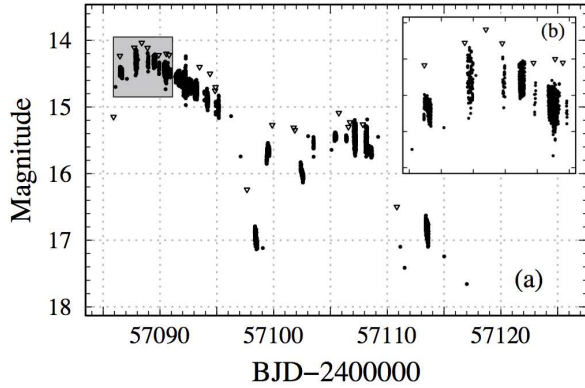


Fig. 1. (a) Overall light curve of AL Com (BJD 2457085 – 2457120). (b) Enlargement light curve around the precursor (BJD 2457086 – 2457091). It is the enlarged view of the shaded box in panel (a). The black circles and inverted triangles represent CCD photometric observations and visual observations, respectively.

Figure 2(a) shows an enlarged light curve on BJD 2457089, on the first night when superhumps appeared. In combination with Figure 1(a), the growth time scale of the superhumps can be determined as ~ 3 d, an unprecedentedly short value among WZ Sge-type dwarf novae. Despite careful analyses before the appearance of the superhumps, no evidence for early superhumps was present. The present superoutburst of AL Com is also the first example in which early superhumps are absent in a superoutburst of WZ Sge-type dwarf novae. In Figure 2(b), an enlarged light curve on BJD 2457105 is depicted. We can see the regrowth of superhumps after the temporary disappearance of superhumps around the dip in the rebrightening phase in Figure 2(b).

Next, we performed a period analysis by using the Phase Dispersion Minimization method (PDM: Stellingwerf 1978) during the plateau stage. In order to subtract a global trend from the light curve, we used locally weighted polynomical regression (LOWESS: Cleveland 1979). The 1σ errors for the PDM analysis were calculated by the methods in Fernie (1989) and Kato et al. (2010). The resultant Θ diagram is shown in the upper panel of Figure 3. The obtained period of $P_{sh} = 0.0573185(11)$ d well agrees with those of previous superoutbursts (Nogami et al. 1997; Kato et al. 2014a).

We show the $O - C$ curve of superhump-maximum timings of AL Com in the upper panel of Figure 4. The light curve during BJD 2457089.3 – 2457095.5 is shown in the lower panel of Figure 4. In the upper panel of Figure 4, the $O - C$ curve

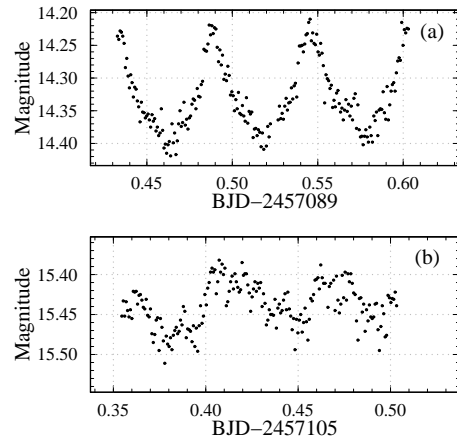


Fig. 2. Light curves of superhumps: (a) superhumps in the main outburst (BJD 2457089.40 – 2457089.65) and (b) those in the rebrightening (BJD 2457105.35 – 2457105.50).

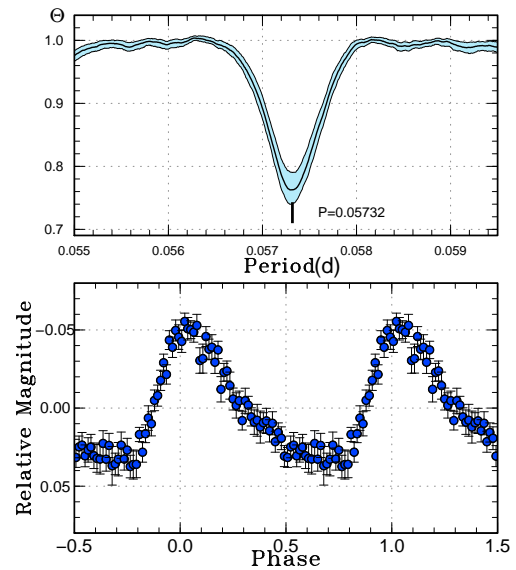


Fig. 3. Superhumps in the plateau stage of the 2015 outburst of AL Com (BJD 2457089.3 – 2457095.5). The upper panel represents Θ -diagram of our PDM analysis. The lower panel represents a phase-averaged profile.

does not seem to be linear. Therefore, we regard superhumps in the plateau stage as stage B superhumps (Kato et al. 2009). We could not find stage A and stage C superhumps in the upper panel of Figure 4. The time derivative of the superhump period $P_{dot} = +1.5(3.1) \times 10^{-5} \text{ s}^{-1}$ was recorded in stage B. This value agrees with those obtained in previous superoutbursts (Nogami et al. 1997; Kato et al. 2009).

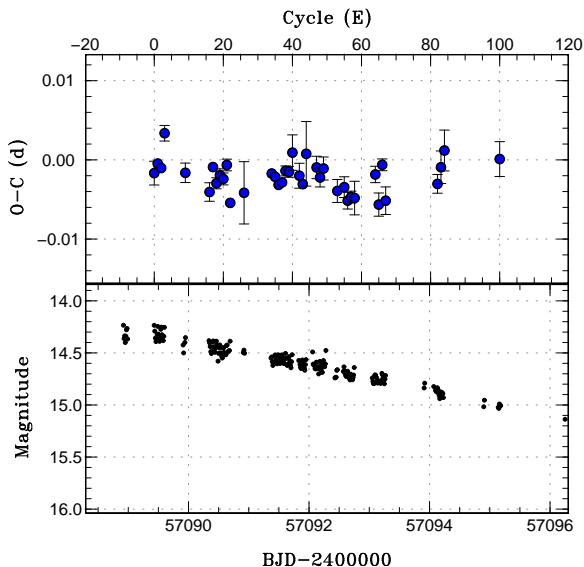


Fig. 4. The upper panel represents the $O - C$ curve of the superhump-maximum timings of AL Com (BJD 2457089.3 – 2457095.5). An ephemeris of BJD 2457089.432681 + 0.057318 E was used for drawing this figure. The lower panel represents the light curve during BJD 2457089.3 – 2457095.5. The horizontal axis in units of BJD and cycle number is common to both of upper and lower panels.

3 Discussion

3.1 Superoutburst

One of the most surprising results is that AL Com exhibited a superoutburst with a recurrence time of ~ 450 d, despite the fact that the AL Com is classified as WZ Sge-type dwarf novae and that a supercycle of the system has been ~ 6 yr over the past 20 years. WZ Sge stars having a short supercycle include AL Com and EZ Lyn. EZ Lyn has the shortest recorded interval between superoutbursts of ~ 4 yr, based on the reported superoutbursts (Pavlenko et al. 2012; Isogai et al. 2015). The present superoutburst of AL Com has established the shortest interval of superoutbursts among WZ Sge-type dwarf novae. At present, the reason why AL Com underwent a superoutburst with such a short interval is unclear; it was likely disk instability was somehow triggered earlier than in past superoutbursts.

3.2 Precursor and Early Superhumps

It should be noted that a precursor was observed for the first time in WZ Sge-type dwarf novae (see Figure 1(b)). In spite of good coverage around the onset of outbursts, the absence of a precursor in WZ Sge-type dwarf novae is confirmed in e.g., GW Lib (Hiroi et al. 2009), V455 And (Matsui et al. 2009), and WZ Sge itself (Ishioka et al. 2002). These systems show large-amplitude and long-lasting superoutbursts compared with the present superoutburst of AL Com. According to the thermal-

tidal instability model, the disk radius of the main superoutburst in which precursors are observed critically exceeds the 3:1 resonance radius during the precursor outburst (see, figure 4 of Osaki, Meyer 2003). In combination with the thermal-tidal instability model and the past investigation of the disk radius variation as reviewed in section 1, the observed precursor in the present superoutburst suggests that the maximum radius of the accretion disk is slightly larger than the 3:1 resonance radius.

It is also noteworthy that the present superoutburst lacked early superhumps. In other words, superhumps appeared ~ 3 d from the onset of the superoutburst. The appearance of the superhumps in the present superoutburst was about a week earlier than those in previous superoutbursts. In fact, Howell et al. (1996) reported that it took 10 d for superhumps to develop during the 1995 superoutburst. According to Lubow (1991), the growth time of the tidal instability is inversely proportional to the square of the mass ratio. Osaki (1995) also followed this interpretation. Instead, Osaki, Meyer (2002) and Osaki, Meyer (2003) proposed that early superhumps are manifestation of the 2:1 resonance radius and that the 2:1 resonance suppresses the development of superhumps. The observed precursor and the lack of early superhumps can be explained as the result of condition that the maximum radius is below the 2:1 resonance. The striking difference of the development of ordinary superhumps on the same object (AL Com) indicates that the mass ratio cannot be the main cause of the long delay of appearance of ordinary superhumps in WZ Sge-type dwarf novae. We can interpret that the 2:1 resonance (and its manifestation, early superhumps) suppresses the development of ordinary superhumps.

3.3 Superhump Period Changes

From the $O - C$ diagram, we derived $P_{\text{dot}} = +1.5(3.1) \times 10^{-5} \text{ s s}^{-1}$. This value is in good agreement with those of previous works (e.g., Kato et al. 2009). Based on the extensive data of P_{dot} , Kato et al. (2009) suggested that each object has the same P_{dot} regardless of whether or not the superoutburst is accompanied by a precursor in ordinary SU UMa-type dwarf novae. The present superoutburst further supports the result of Kato et al. (2009) even in WZ Sge-type ones.

3.4 Rebrightening

Although the plateau stage of the present superoutburst was similar to those of SU UMa-type dwarf novae, a long rebrightening (type-A rebrightening) was observed in the present outburst of AL Com. AL Com showed the type-A (or type A/B) rebrightening also in all of the previous superoutbursts (Nogami et al. 1997; Ishioka et al. 2002; Uemura et al. 2008; Kato et al. 2014a; Kato 2015). In the 2015 outburst, the rebrightening type was the same as previous ones in spite that the stored disk mass just before the outburst should have been much less than previ-

ous ones, which means that the rebrightening type of AL Com is the same regardless of the extent of outburst. It may be possible that the matter remained outside the 3:1 resonance if the radius of the 3:1 resonance is well inside the Roche lobe. The uniqueness of the type of the rebrightening within the same object is recorded not only in AL Com but also in other WZ Sge-type dwarf novae. For example, EZ Lyn showed only type-B rebrightening. Another example is the 2003-04 and 2013 superoutbursts of UZ Boo, which showed only type-B rebrightening (Kato 2015). Kato et al. (2014a) studied the relation between P_{dot} and P_{orb} in terms of the type of the rebrightening, in which each type of the rebrightening pattern is clustered on the $P_{\text{dot}} - P_{\text{orb}}$ diagram (see figure 83 of Kato et al. (2014a)). In conjunction with the present study and the $P_{\text{dot}} - P_{\text{orb}}$ diagram, the type of the rebrightening seems to be inherent in the same system. This reproducibility of rebrightening type needs to be explained by theoretical investigations.

As shown in Figure 2(b), a regrowth of the superhumps was observed during the rebrightenings. This suggests that the accretion disk again extended beyond the 3:1 resonance radius over the course of the rebrightenings.

4 Summary

We have reported unusual superoutburst and rebrightening of AL Com in 2015 March. We summarize the most important results of our observations as follows:

1. AL Com showed a superoutburst with an interval of ~ 450 d. This interval is the shortest record among WZ Sge-type dwarf novae.
2. The light curve showed a precursor and lacked early superhumps, which is the first example in the superoutbursts of WZ Sge-type dwarf novae. The presence of the precursor and the lack of early superhumps suggest that the maximum disk radius of this superoutburst barely exceeded the 3:1 resonance and did not reach the 2:1 resonance radius following the theory proposed by Osaki, Meyer (2002) and Osaki, Meyer (2003).
3. AL Com showed the type-A rebrightening in the present superoutburst, despite the fact that the main superoutburst mimicked the typical one in ordinary SU UMa-type dwarf novae, and despite that the mass stored in the accretion disk at the onset of the superoutburst is supposed to be much smaller than those in previous superoutbursts of AL Com.

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Table 1. Log of observations of AL Com in 2015

Start*	End*	Mag [†]	Error [‡]	N [§]	Obs	Band [#]	exp[s]
86.4595	86.6849	14.253	0.002	307	RPc	V	60
87.8162	87.9366	14.116	0.011	72	AAVSO	V	120
89.4328	89.6030	14.326	0.004	214	DPV	C	60
90.3395	90.4716	14.437	0.004	170	DPV	C	60
90.4260	90.6889	14.261	0.003	285	RPc	V	60
90.4903	90.5754	14.225	0.006	120	AAVSO	V	60
91.3727	91.6040	14.572	0.002	285	DPV	C	60
91.5368	91.7189	14.356	0.003	248	RPc	V	60
91.8336	91.9516	14.418	0.004	100	AAVSO	V	120
91.8388	91.9311	14.376	0.004	92	DKS	C	60
92.0640	92.2760	14.215	0.004	541	Kis	Ic	30
92.4319	92.7412	14.498	0.003	267	RPc	V	60
92.7250	92.7544	14.454	0.009	29	DKS	C	60
93.0458	93.2710	14.588	0.002	511	Kis	C	30
94.0966	94.2286	14.718	0.003	347	Kis	C	30
95.1349	95.1804	14.844	0.005	121	Kis	C	30
98.3414	98.5572	16.985	0.006	140	DPV	C	60
99.3920	99.6271	15.643	0.003	302	DPV	C	60
102.3807	102.6172	15.993	0.005	159	DPV	C	60
103.5077	103.5213	15.927	0.015	20	AAVSO	V	60
105.3546	105.5033	15.439	0.002	191	DPV	C	60
106.3781	106.4277	15.466	0.003	65	DPV	C	60
107.0658	107.2406	15.276	0.004	457	Kis	C	30
108.0868	108.2301	15.326	0.006	247	Kis	C	30
108.2852	108.5968	14.823	0.002	273	CRI	C	90
108.4375	108.6461	15.331	0.002	290	RPc	C	60
108.3752	108.5311	15.313	0.002	194	IMi	C	60
113.3872	113.6240	16.518	0.006	257	IMi	C	60

*BJD – 2457000.0.

[†]Mean magnitude.[‡]1 σ of mean magnitude.[§]Number of observations.^{||}Observer's code: RPc (Roger D. Pickard),

AAVSO (AAVSO observers: Boardman James and Rodda Anthony),

DPV (Pavol A. Dubovsky), DKS (Shawn Dvorak), Kis (Seiichiro Kiyota),

CRI (Elena P. Pavlenko and Aleksei A. Sosonovskij), and IMi (Ian Miller)

[#]Filter. "V" means V filter, "C" means no filter (clear),

and "Ic" means I filter with unfiltered zeropoint.